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DESCRIPTION

CAM LOBE MATERIAL, CAM SHAFT USING THE SAME AND METHOD OF MANUFACTURING CAM LOBE MATERIAL

Technical Field

[0001]

The present invention relates to a cam lobe material used in an internal combustion engine, a cam shaft that uses the cam lobe material, and a method of manufacturing the cam lobe material.

Background Art

[0002]

As a cam shaft of a valve train used in an internal combustion engine, there has been known an assembly type cam shaft provided with a cam lobe in a shaft. The cam lobe to be provided in the cam shaft is divided into a type in which a cam follower that makes rolling contact (a roller follower) is used as a mating member and a type in which a cam follower that makes sliding contact (slide contact) (a slipper follower) is used as a mating member (refer to Patent Document 1, for example).

[0003]

In such an internal combustion engine, parts such as cam shaft and rocker arm slide at high speeds during operation and hence they are required to have sliding characteristics.

Particularly, in the above-described cam lobe that uses a roller follower making roller contact as a mating member, the area of contact with the roller follower is small and hence this cam lobe is required in its peripheral surface to be excellent in all of the sliding characteristics of wear resistance, pitting resistance and scuffing resistance.

[0004]

For this reason, there has hitherto been used a cam shaft that is provided with a chilled cam in which a cam nose part is rapidly cooled and caused to solidify during casting by using a chiller in this part, whereby a hard white cast iron structure is formed in the surface part of the cam nose. This chilled cam shaft, which has a hard chilled structure on its peripheral surface, has excellent wear resistance and scuffing resistance.

[0005]

On the other hand, in an assembly type cam shaft, there have been known techniques that involve improving the density of a cam piece by warm forming the cam piece thereby to solve the problem that a cam piece is broken during the diameter expanding of a shaft (refer to, Patent Document 2, for example).

Patent Document 1: Japanese Patent Laid-Open No. 2001-240948

Patent Document 2: Japanese Patent Laid-Open No. 2003-14085

Disclosure of the Invention

Problem to be Solved by the Invention

[0006]

However, chilled cam shafts had the problem that they are inferior in pitting resistance. For this reason, chilled cam shafts had the problem that it is difficult to use them in engines to which high loads are applied.

[0007]

Furthermore, there is a limit to an improvement in the density of cam pieces by warm forming, and as with chilled cam shafts, cam pieces had the problem that it is difficult to use them in engines to which high loads are applied.

[0008]

Therefore, by solving these problems, the present invention has as its object the provision of a cam lobe material that is excellent in sliding characteristics, such as wear resistance, pitting resistance and scuffing resistance, and can be advantageously used in engines to which high loads are applied, a cam shaft using this cam lobe material, and a method of manufacturing the cam lobe material

Means for Solving the Problem

[0009]

A cam lobe material of a present invention for solving the above-mentioned problem is the cam lobe material formed from an iron-based sintered alloy that contains 0.3 to 5.0 mass% Ni, 0.5 to 1.2 mass% C, 0.02 to 0.3 mass% of at least either of B and P, and incidental impurities as the balance, and has a hardness of a peripheral surface of not less than HRC 50 and a density of not less than 7.5 g/cm^3.

[0010]

According to the invention, because a cam lobe material is fabricated from an iron-based alloy having a specific chemical composition, it is possible to provide a high-hardness, high-density cam lobe material. Particularly, because at least either of B and P is contained, the density of a manufactured cam lobe material can be increased by causing a liquid phase to be formed during sintering. As a result, a cam lobe material of the invention is excellent in sliding characteristics such as wear resistance, scuffing resistance and pitting resistance. For this reason, it is possible to provide a cam lobe that can be advantageously used even in engines to which high loads are applied, for example, an engine to which a compressive load that is about twice the compression load in usual engines is applied.

[0011]

In the cam lobe material of the present invention mentioned above, the iron-based sintered alloy further contains not more than 2.5 mass% Mo. According to the present invention, in addition to the above advantage, it is possible to obtain a cam lobe material in which the solid solution effect of the iron-based alloy matrix is enhanced by increasing the hardenability of the cam lobe material after sintering.

[0012]

In the cam lobe material of the present invention mentioned above, the cam lobe material uses a roller follower as a mating member. According to the present invention, owing to its

toughness and hardness a cam lobe material is improved in its repeated contact fatigue strength and, therefore, this cam lobe can be advantageously used as a mating member of a roller follower that is required to have contact fatigue strength represented by pitting resistance.

[0013]

A cam shaft of a present invention for solving the above-mentioned problem is the cam shaft provided with a cam lobe formed from the cam lobe material according to the present invention mentioned above. According to the present invention, it is possible to provide a cam shaft that is excellent in sliding characteristics such as wear resistance, scuffing resistance and pitting resistance and can be advantageously used even in engines to which high loads are applied.

[0014]

A method of manufacturing the cam lobe material of a present invention for solving the above-mentioned problem is the method of manufacturing the cam lobe material according to the present invention mentioned above, a compression molding step and a sintering step are repeated at least twice, the compression molding step involving compression molding iron-based alloy powders prepared so as to provide the composition of the ferrous sintered alloy in a prescribed cam lobe shape, and the sintering step involving sintering the compression molded compact body, and that the sintered body is subjected to quench and tempering treatment.

[0015]

According to the present invention, the dimensional accuracy before and after the final sintering step is high and cutting after the manufacture of a cam lobe is unnecessary or the amount of cutting is small. For this reason, the labor and cost necessary for the manufacture of a cam lobe can be reduced. Furthermore, it is possible to obtain a hardness of a peripheral surface of not less than HRC 50 and a density of not less than 7.5 g/cm^3. For this reason, high hardness and high density can be ensured in a cam lobe material after manufacture and it is possible to obtain a cam lobe material excellent in sliding characteristics such as wear resistance, scuffing resistance and pitting resistance. Therefore, it is possible to provide a cam lobe that can be advantageously used even in engines to which high loads are applied, for example, an engine to which a compressive load that is about twice the compressive load in usual engines is applied.

[0016]

In the method of manufacturing the cam lobe material of the present invention mentioned above, the peripheral surface of the cam lobe material is shot blasted. According to the present invention, the pitting resistance of a cam lobe material can be improved by performing shot blasting.

Effect of the Invention

[0017]

As described above, a cam lobe material of the invention is made of an iron-based alloy of a specific chemical composition and, therefore, it is possible to provide a high-hardness, high-density cam lobe material. Particularly, because at least either of B and P is contained, the density of a manufactured cam lobe material can be increased by causing a liquid phase to be formed during sintering. As a result, a cam lobe material of the invention is excellent in sliding characteristics such as wear resistance, scuffing resistance and pitting resistance. For this reason, it is possible to provide a cam lobe that can be advantageously used even in engines to which high loads are applied, for example, an engine to which a compressive load that is about twice the compressive load in usual engines is applied. And a cam lobe material of the invention can be advantageously used as a mating member of a roller type cam follower.

[0018]

Also, according to a method of manufacturing a cam lobe material of the present invention, the dimensional accuracy before and after the final sintering step is high and cutting after the manufacture of a cam lobe is unnecessary or the amount of cutting is small. For this reason, the labor and cost necessary for the manufacture of a cam lobe can be reduced. Furthermore, it is possible to obtain a hardness of a peripheral surface of not less than HRC 50 and a density of not less than 7.5 g/cm^3. For this reason, high hardness and high density can be ensured in a cam lobe material after manufacture and

it is possible to obtain a cam lobe material excellent in sliding characteristics such as wear resistance, scuffing resistance and pitting resistance. Therefore, it is possible to provide a cam lobe that can be advantageously used even in engines to which high loads are applied, for example, an engine to which a compressive load that is about twice the compressive load in usual engines is applied.

Brief Description of the Drawings

[0019]

FIGS. 1A and 1B are respectively a perspective view of an aspect of a valve train of an internal combustion engine provided with a cam lobe material of the invention and a plan view of a cam shaft of the invention;

FIG. 2 is a schematic diagram of a double cylinder contact testing machine used in the evaluation of embodiments of the invention;

FIG. 3 is a graph that shows the relationship between the density of a cam lobe material and the Ni (nickel) content in embodiments of the invention;

FIG. 4 is a graph that shows the relationship between the hardness of a cam lobe material and the Ni content in embodiments of the invention;

FIG. 5 is a graph that shows the relationship between the frequency of occurrence of pitting of a cam lobe material and the Ni content in embodiments of the invention;

FIG. 6 is a graph that shows the relationship between the rate of dimensional change of a cam lobe material and the Ni content in embodiments of the invention;

FIG. 7 is a graph that shows the relationship between cam lift errors of a cam lobe material and the Ni content in embodiments of the invention;

FIG. 8 is a graph that shows the relationship between the density of a cam lobe material and the C (carbon) content in embodiments of the invention;

FIG. 9 is a graph that shows the relationship between the hardness of a cam lobe material and the C content in the embodiments of the invention;

FIG. 10 is a graph that shows the relationship between the density of a cam lobe material and the P (phosphorus) content in embodiments of the invention;

FIG. 11 is a graph that shows the relationship between the hardness of a cam lobe material and the P content in embodiments of the invention;

FIG. 12 is a graph that shows the relationship between the frequency of occurrence of pitting of a cam lobe material and the P content in embodiments of the invention;

FIG. 13 is a graph that shows the relationship between the density of a cam lobe material and the B (boron) content in embodiments of the invention;

FIG. 14 is a graph that shows the relationship between the hardness of a cam lobe material and the B content in embodiments of the invention;

FIG. 15 is a graph that shows the relationship between the density of a cam lobe material and the Mo (molybdenum) content in embodiments of the invention; and

FIG. 16 is a graph that shows the relationship between the hardness of a cam lobe material and the Mo content in embodiments of the invention.

Explanation of symbols

[0020]

1 Cam lobe material (a rolling contact type)

2 Cam shaft

3 Roller follower (a rolling contact type cam flower)

4 Valve train of an internal combustion engine

5 Cam lobe material (a sliding contact type)

6 Slipper follower (a sliding contact type cam follower)

7 Shaft

8 Test piece of cam lobe material

9 Cylindrical test piece of mating material

10 Lubricating oil

11 Load

Best Mode for Carrying Out the Invention

[0021]

A cam lobe material, a cam shaft and a method of manufacturing the cam lobe material of the invention will be described below.

[0022]

A cam lobe material of the invention is formed from an iron-based sintered alloy that contains 0.3 to 5.0 mass% Ni, 0.5 to 1.2 mass% C, 0.02 to 0.3 mass% of at least either of B and P, and incidental impurities as the balance, and has a hardness of a peripheral surface of not less than HRC 50 and a density of not less than 7.5 g/cm^3. The iron-based sintered alloy can further contain not more than 2.5 mass% Mo.

[0023]

First, the iron-based sintered alloy is described.

[0024]

Ni (Nickel) has the action of increasing strength and toughness. The specified Ni content is 0.3 to 5.0 mass%. If the Ni content is less than 0.3 mass%, sufficient strength and toughness cannot be obtained. On the other hand, if the Ni content exceeds 5.0 mass%, the amount of dimensional change during sintering increases, thereby worsening accuracy. It is preferred that Ni be contained in an amount of 1.0 to 3.0 mass%.

[0025]

C (carbon) has the action of capable of obtaining the hardness of a cam peripheral surface that satisfies wear resistance. The specified C content is 0.5 to 1.2 mass%. If the C content is less than 0.5 mass%, it is difficult to obtain a desired hardness of a peripheral surface of a cam after quench and tempering treatment and the peripheral surface of a cam is inferior in wear resistance. On the other hand, if the

C content exceeds 1.2 mass%, compressibility decreases greatly and density does not increase. It is preferred that C be contained in an amount of 0.8 to 1.0 mass%.

[0026]

B (boron) and P (phosphorus) have the action of promoting sintering by forming a low-melting-point ternary eutectic liquid phase with Fe (iron) and C. At least either of B and P is contained in an iron-based sintered alloy of a cam lobe material of the invention. The content of at least either of B and P is 0.02 to 0.3 mass%. If the content of at least either of B and P is less than 0.02 mass%, the above-described action is weak and the density and hardness that will be described later may not sometimes be obtained. On the other hand, if the content of at least either of B and P exceeds 0.3 mass%, the amount of shrinkage during sintering increases and the dimensional accuracy of a cam lobe material worsens. It is preferred that at least either of B and P be contained in an amount of 0.05 to 0.20 mass%. Incidentally, when both B and P are to be contained, usually the ratio of content of B and P should be B:P = 2:1 to 1:2 or so although this ratio is not especially limited.

[0027]

Mo (molybdenum) that is arbitrarily added has the action of increasing hardenability and promoting the solid solution effect of the iron-based alloy matrix. The specified Mo content is not more than 2.5 mass%. Although the effect of Mo is obtained little by little from a content of 0.05 mass%

or so, compressibility worsens greatly and density does not increase if the Mo content exceeds 2.5 mass%. It is preferred that Mo be contained in an amount of 0.2 to 1.5 mass% or so.

[0028]

Incidentally, incidental impurities as the balance include residues of lubricants such as zinc stearate added to sintering powders and of components of other additives in addition to trace amounts of impurities that mix into raw material powders.

[0029]

Subsequently, a description will be given of the physical properties of a cam lobe material formed from the above-described iron-based sintered alloy.

[0030]

The hardness of the peripheral surface of a cam lobe material should be not less than HRC 50. If this hardness is less than HRC 50, wear resistance cannot be satisfied. An upper limit to the hardness of the peripheral surface of a cam lobe material is usually HRC 60 or so although this upper limit is not especially limited. It is preferred that the hardness of the peripheral surface be HRC 50 to 55. The peripheral surface of a cam lobe material is the surface that slides with a cam follower when the cam lobe material is used in a cam shaft as a cam lobe.

[0031]

The density of a cam lobe material should be not less than 7.5 g/cm^3. If the density is less than 7.5 g/cm^3, strength

decreases due to the porosities of a cam lobe material and pitting resistance worsens. Therefore, the cam lobe material cannot be used in engines to which high loads are applied. Incidentally, an upper limit to the density of a cam lobe material is usually 7.7 g/cm^3 or so although this upper limited is not especially limited. It is preferred that the density be 7.5 to 7.6 g/cm^3.

[0032]

Because as described above a cam lobe material of the invention has high density and high hardness, the cam lobe material has high pitting resistance in the contact with a cam follower. For this reason, a cam lobe fabricated from a cam lobe material of the invention can be advantageously used in engines to which high loads are applied. Furthermore, a cam lobe material of the invention is also excellent in wear resistance and scuffing resistance and in sliding characteristics as well.

[0033]

A cam lobe material of the invention is advantageously used as a mating member of a roller type cam follower (a roller follower). FIG. 1A is a perspective view of a valve train 4 of an internal combustion engine to show how a cam shaft 2 provided with a cam lobe 1 formed from a cam lobe material of the invention is in contact with a roller follower (rolling contact type cam flower) 3. Incidentally, on the forward side of FIG. 1A are shown a cam lobe 5 provided on a cam shaft 2

and a slipper follower (a sliding contact type cam follower) 6.

[0034]

A roller tappet, a roller rocker arm, etc. can be enumerated as this roller follower 3. Such a roller follower 3 and the cam lobe material 1 that is a mating member of this roller follower are required to have repeated contact fatigue strength represented by pitting resistance. In the invention, a liquid phase is formed by the component of B or/and P during the sintering of a cam lobe material and the cam lobe material is densified to increase its density. The toughness and hardness of a cam lobe material are improved in this manner and the repeated contact fatigue strength is improved. For this reason, a cam lobe material of the invention can be advantageously used as a mating member of a roller follower.

[0035]

Incidentally, by using the above-described cam lobe material of the invention it is possible to provide a cam shaft 2 as described in FIGS. 1A and 1B. Aspects and manufacturing method of this cam shaft 2 will be described later.

[0036]

Subsequently, a method of manufacturing a cam lobe material of the invention will be described. This manufacturing method applies to only the above-described cam lobe material of the invention.

[0037]

A method of manufacturing a cam lobe material of the invention involves using iron-based alloy powders blended and prepared to obtain an iron-based sintered alloy of the above-described composition, repeating a compression molding step and a sintering step at least twice and performing quench and tempering treatment. Furthermore, the peripheral surface of the cam lobe material can be shot blasted.

[0038]

The components, blending ratios, actions, etc. of elements to be added to the iron-based alloy powders are the same as in the description of the above cam lobe material. The iron-based alloy powders are blended and prepared so as to obtain component ratios within the above-described ranges after sintering.

[0039]

A description will be given of the compression molding step that involves mixing such iron-based alloy powders in such a manner as to ensure that each component is uniformly mixed and compression molding the iron-based alloy powders to a prescribed shape. This compression molding step is performed at least twice. Incidentally, the second and later compression molding steps are performed after the sintering step.

[0040]

This compression molding step is performed by use of a hitherto publicly known compression molding device, and usually press forming is performed by use of a mechanical press

etc. The compressive load during compression molding is usually 5 to 7 tons/cm^2 or so in the compression molding step (temporary molding) except the final compression molding. In the final compression molding step, the compressive load is higher than in temporary molding and usually 7 to 12 tons/cm^2 or so. Incidentally, the temperature in the compression molding step is the same as usually and 20 to 40°C or so.

[0041]

A description will be given of the sintering step in which after the compression molding of the iron-based alloy powders in this manner, a compact body is sintered. This sintering step is performed at least twice.

[0042]

This sintering step can be performed by use of a hitherto publicly known sintering device, and usually it is performed by use of a vacuum sintering furnace etc. The temperature in the sintering step is usually 650 to 850°C or so in the sintering step (temporary sintering) except the final sintering step. In the final sintering step, the sintering temperature is higher than in temporary sintering and usually 1100 to 1200°C or so, preferably 1130 to 1180°C or so. The atmosphere surrounding a compact body in the sintering step is the same as the atmosphere during usual sintering and is not especially limited. Sintering is performed in an atmosphere of Ax gas, Rx gas, vacuum, etc. The time required by the sintering of a compact body of a cam lobe material is

the same as usual sintering time and is not especially limited. This sintering time is 30 to 90 minutes or so.

[0043]

Next, the sintered body of the cam lobe material obtained in the final sintering step is subjected to quench and tempering treatment. The quenching treatment is performed by holding the sintered body at 800 to 950°C for 30 to 150 minutes or so usually in a heat treatment furnace etc. and then quenching the sintered body to 30 to 100°C or so by use of oil, water, etc. The tempering treatment is performed usually at 120 to 200°C for 30 to 150 minutes or so after the above-described quenching treatment and then performing cooling to 10 to 40°C or so at a rate of 2 to 10°C/minute or so. The quench and tempering treatment enables the wear resistance of a cam lobe to be improved by increasing the hardness of the peripheral surface of the cam.

[0044]

It is preferred that the peripheral surface of a sintered body of a cam lobe material be further shot blasted. Residual compressive stresses are caused to be generated on the peripheral surface of the cam lobe material by performing shot blasting, thereby to improve pitting resistance. Usually shot blasting is performed by rotating the cam lobe material, adjusting a nozzle so as to be able to shot the peripheral surface, and causing grits of steel, glass beads, etc. to strike against the peripheral surface of the cam lobe material at a pressure of 5 kg/cm^2 or so.

[0045]

Incidentally, in a cam lobe material manufactured by a method of manufacturing a cam lobe material of the invention, the rate of dimensional change before and after the final sintering step becomes +- (±)0 to 0.5% or so. This rate of dimensional change is obtained by measuring the peripheral shapes of a compact body before the final sintering step and of a sintered body after the final sintering step at a minimum of one point per degree over 360 degrees by use of a three-dimensional measuring machine, determining the rate of dimensional change at each measuring point by superposing the two shapes that are traced from the measuring points, and finding a maximum value among the dimensional changes at the measuring points.

[0046]

Thus, according to a method of manufacturing a cam lobe material of the invention, because a cam lobe material undergoes the compression molding step and the sintering step at least twice, the dimensional accuracy before and after the final sintering step is high and cutting after the manufacture of a cam lobe material is unnecessary or the amount of cutting is small. For this reason, the labor and cost necessary for the manufacture of a cam lobe can be reduced. Furthermore, it is possible to obtain a hardness of a peripheral surface of not less than HRC 50 and a density of not less than 7.5 g/cm^3. For this reason, high hardness and high density can be ensured in a cam lobe material after manufacture and it

is possible to obtain a cam lobe material excellent in sliding characteristics such as wear resistance, scuffing resistance and pitting resistance. Therefore, it is possible to provide a cam lobe material that can be advantageously used even in engines to which high loads are applied, for example, an engine to which a compressive load that is about twice the compressive load in usual engines is applied.

[0047]

Incidentally, by assembling a cam lobe material thus manufactured on a shaft and fixing the cam lobe material, an assembly type cam shaft 2 as shown in Fig. 1B is obtained. This cam shaft 2 is obtained by assembling a cam lobe material by shrinkage fit or cooling fit in a prescribed position of the shaft 7 that is formed, for example, from a material such as S45C at a prescribed angle and fixing the cam lobe material. As a method of assembling a cam lobe material on a shaft and fixing the cam lobe material, the above-described shrinkage fit and cooling fit are desirable from the standpoint of assembling accuracy and inexpensive equipment cost. However, it is also possible to adopt other methods such as press fit and diffusion bonding. Also, this cam shaft 2 may be provided with only the cam lobe 1 formed from a cam lobe material of the invention or as shown in Fig. 1A, the cam shaft 2 may be provided with both the cam lobe 1 according to the invention and a cam lobe 5 having sliding characteristics suitable for a sliding type cam follower 6. The cam shaft thus manufactured does not require cutting the cam lobe at all or requires only

a very little amount of cutting even if cutting is necessary. Thus, it is possible to provide a cam shaft that is excellent in sliding characteristics such as wear resistance, scuffing resistance and pitting resistance and can be advantageously used in engines to which high loads are applied.

Embodiments

[0048]

The present invention will be described more concretely below with reference to embodiments and comparative examples.

[0049]

(Embodiments 1 to 30)

Sintering powders were prepared by adding each element to an iron powder so as to obtain the final component compositions shown in Table 1, and the sintering powders were compression molded in cam lobe shape at a compressive load of 6 tons/cm^2 and then sintered at 700°C for 90 minutes. Furthermore, this sintered body was compression molded in cam lobe shape at a compressive load of 10 tons/cm^2 and then sintered at 1140°C for 60 minutes. Subsequently, this sintered body was heated at 900°C for 100 minutes and after that, quenching treatment was performed by oil quenching. Furthermore, this sintered body was heated at 150°C for 60 minutes and after that, tempering treatment was performed by air cooling. After that, shot blasting was performed and the cam lobe materials of Embodiments 1 to 30 were obtained.

[0050]

(Comparative Example 1)

Each element was caused to melt so as to obtain the final component composition shown in Table 1, the melt was poured into a mold having a chiller and rapidly cooled, and chilled cast iron was obtained by causing the melt to solidify. The cam lobe material of Comparative Example 1 was fabricated by polishing the chilled cast iron.

[0051]

(Comparative Examples 2 to 5)

Sintering powders were prepared by adding each element to an iron powder so as to obtain the final compositions shown in Table 1, and the sintering powders were compression molded in cam lobe shape at a compressive load of 5 tons/cm^2 and then sintered at 1100°C for 60 minutes, whereby the cam lobe materials of Comparative Examples 2 to 5 were obtained.

[0052]

[Table 1]

	Final composition / mass %									
	C	Ni	Cu	B	P	Mo	Si	Mn	Cr	Fe
Embodiment1	0.8	0.5	–	–	0.1	–	–	–	–	Balance
Embodiment2	0.8	1.0	–	–	0.1	–	–	–	–	Balance
Embodiment3	0.8	2.0	–	–	0.1	–	–	–	–	Balance
Embodiment4	0.8	2.5	–	–	0.1	–	–	–	–	Balance
Embodiment5	0.8	3.0	–	–	0.1	–	–	–	–	Balance
Embodiment6	0.8	3.5	–	–	0.1	–	–	–	–	Balance
Embodiment7	0.8	4.5	–	–	0.1	–	–	–	–	Balance
Embodiment8	0.8	5.0	–	–	0.1	–	–	–	–	Balance
Embodiment9	0.5	3.5	–	0.05	–	–	–	–	–	Balance
Embodiment10	0.8	3.5	–	0.05	–	–	–	–	–	Balance
Embodiment11	1.0	3.5	–	0.05	–	–	–	–	–	Balance
Embodiment12	1.2	3.5	–	0.05	–	–	–	–	–	Balance
Embodiment13	0.8	0.5	–	–	0.05	–	–	–	–	Balance
Embodiment14	0.8	0.5	–	–	0.2	–	–	–	–	Balance
Embodiment15	0.8	0.5	–	–	0.3	–	–	–	–	Balance
Embodiment16	0.8	3.5	–	–	0.2	–	–	–	–	Balance
Embodiment17	0.8	3.5	–	0.02	–	–	–	–	–	Balance
Embodiment18	0.8	3.5	–	0.1	–	–	–	–	–	Balance
Embodiment19	0.8	3.5	–	0.3	–	–	–	–	–	Balance
Embodiment20	0.8	3.5	–	–	0.1	0.3	–	–	–	Balance
Embodiment21	0.8	3.5	–	–	0.1	1.0	–	–	–	Balance
Embodiment22	0.8	3.5	–	–	0.1	2.0	–	–	–	Balance
Embodiment23	0.8	3.5	–	–	0.1	2.5	–	–	–	Balance
Embodiment24	1.0	3.5	–	0.05	–	0.3	–	–	–	Balance
Embodiment25	1.0	3.5	–	0.05	–	1.0	–	–	–	Balance
Embodiment26	1.0	3.5	–	0.2	–	2.0	–	–	–	Balance
Embodiment27	1.0	2.0	–	0.1	–	0.3	–	–	–	Balance
Embodiment28	1.0	3.0	–	0.2	–	1.0	–	–	–	Balance
Embodiment29	1.0	1.0	–	0.2	–	2.0	–	–	–	Balance
Embodiment30	1.0	1.0	–	0.2	0.2	2.0	–	–	–	Balance

[Table 1 continue]

	Final composition / mass %									
	C	Ni	Cu	B	P	Mo	Si	Mn	Cr	Fe
Comparative example 1	3.4	(Ni+Cu)2.0		–	–	2.0	2.0	0.7	0.8	Balance
Comparative example2	0.8	2.0	–	–	–	–	–	–	–	Balance
Comparative example3	0.8	–	–	–	0.05	–	–	–	–	Balance
Comparative example4	0.3	0.2	–	–	0.01	–	–	–	–	Balance
Comparative example5	1.5	6.0	–	–	0.4	–	–	–	–	Balance

[0053]

(Evaluation method and results)

For the cam lobes obtained in each embodiment and each comparative example, (1) density, (2) Rockwell hardness HRC of peripheral surface, (3) frequency of occurrence of pitting and wear losses, (4) rate of dimensional change, and (5) cam lift errors were measured. Measuring methods of each item will be described below and the results of the measurements of each item are shown in Table 2.

[0054]

(1) Density

Test pieces from the obtained cam lobe materials were sealed with paraffin and density was measured by the Archimedes' method.

[0055]

(2) Rockwell hardness of peripheral surface

The periphery of a cam nose of a test piece of each of the obtained cam lobe materials was measured at five points on the C scale by use of a Rockwell hardness meter, and an average value of measurements was calculated as the Rockwell hardness of a peripheral surface.

[0056]

(3) Frequency of occurrence of pitting and wear losses

The frequency of occurrence of pitting and wear loss were measured as follows. By use of a double cylinder contact testing machine shown in FIG. 2, rotary surfaces of each test piece 8 of the cam lobe material rotating at a constant speed and a cylindrical test piece 9 of the mating member were brought into contact with each other and caused to rotate by applying a prescribed load 11 while a lubricating oil 10 was caused to drop onto the contact surfaces of the two test pieces, and the number of revolutions until the occurrence of pitting was measured as the frequency of occurrence of pitting. Also, by rotating each test piece 8, the amount of sinking due to wear (μm) for a given number of revolutions (1×10^5 times) was measured as wear loss.

[0057]

(Measuring conditions)

Measuring device: Double cylinder contact testing machine

Number of revolutions: 1500 rpm

Lubricating oil: Engine oil 10W30

Oil temperature: 100°C

Oil volume: 2×10^{-4} m^3/min

Load: 3000 N

Slip ratio: 0%

Mating member: SUJ2

Judgment method: A crack of the occurrence of pitting was detected from AE (acoustic emission), an S-N curve was prepared by using the frequency of contact at that time as the frequency of occurrence of pitting, and a comparison with each test piece was made.

[0058]

(4) Rate of dimensional change

The peripheral shapes of a secondary compact body and a secondary sintered body were measured at a minimum of one point per degree over 360 degrees by use of a three-dimensional measuring machine, the rate of dimensional change at each measuring point was determined by superposing the two shapes that are traced from the measuring points, and a maximum value among the dimensional changes at the measuring points was found as the rate of dimensional change of the secondary sintered body relative to the secondary compact body. Incidentally, for Comparative Examples 2 to 5, for which compression molding and sintering were performed only once, the rate of dimensional change was measured for the peripheral shapes of a primary compact body and a primary sintered body.

[0059]

(5) Cam lift errors

Cam lift errors were measured for test pieces obtained by shot blasting secondary sintered bodies that had been

subjected to quench and tempering treatment. Cam profiles were measured by use of an adcall for a cam profile measuring program and compared with a target profile, and errors were detected as lift errors. Incidentally, for Comparative Examples 2 to 5, for which compression molding and sintering were performed only once, cam lift errors were measured for test pieces after quench and tempering treatment of primary sintered bodies.

[0060]

[Table 2]

	Density g/cm^3	Hardness HRC	Frequency of occurrence of pitting	Wear loss μm / 1 × 10^5 times	Rate of dimensional change %(absolute value)	Cam lift errors mm(absolute value)
Embodiment1	7.52	52.5	1.2×10^6	0.22	−0.1	0.02
Embodiment2	7.53	53.0	1.6×10^6	0.19	−0.1	0.02
Embodiment3	7.55	53.0	1.5×10^6	0.21	−0.3	0.04
Embodiment4	7.55	53.5	5.0×10^6	0.23	−0.3	0.03
Embodiment5	7.55	54.0	4.3×10^6	0.20	−0.4	0.04
Embodiment6	7.56	55.0	4.0×10^6	0.22	−0.4	0.04
Embodiment7	7.58	55.0	4.5×10^6	0.21	−0.5	0.05
Embodiment8	7.58	55.5	6.0×10^6	0.21	−0.5	0.04
Embodiment9	7.55	51.5	1.5×10^6	0.25	−0.1	0.02
Embodiment10	7.52	53.5	2.5×10^6	0.21	−0.3	0.03
Embodiment11	7.52	53.5	2.0×10^6	0.18	−0.3	0.02
Embodiment12	7.51	55.5	2.2×10^6	0.19	−0.3	0.03
Embodiment13	7.51	52.0	8.5×10^5	0.23	−0.1	0.03
Embodiment14	7.52	53.5	1.1×10^6	0.20	−0.2	0.03
Embodiment15	7.54	54.0	1.5×10^6	0.21	−0.2	0.03
Embodiment16	7.56	54.5	3.9×10^6	0.23	−0.3	0.02
Embodiment17	7.51	53.5	2.0×10^6	0.21	−0.2	0.03
Embodiment18	7.53	54.0	3.2×10^6	0.22	−0.2	0.02
Embodiment19	7.52	53.0	2.8×10^6	0.24	−0.4	0.04
Embodiment20	7.53	55.5	2.5×10^6	0.20	−0.1	0.03
Embodiment21	7.51	56.0	2.2×10^6	0.20	−0.1	0.03
Embodiment22	7.50	56.5	2.0×10^6	0.21	0	0.03
Embodiment23	7.50	56.5	2.0×10^6	0.19	−0.2	0.04
Embodiment24	7.51	55.5	3.1×10^6	0.16	−0.3	0.01
Embodiment25	7.51	56.0	3.5×10^6	0.21	−0.4	0.03
Embodiment26	7.50	56.5	2.0×10^6	0.17	0	0.03
Embodiment27	7.54	55.5	2.1×10^6	0.18	−0.3	0.04
Embodiment28	7.52	56.0	2.0×10^6	0.21	−0.2	0.04
Embodiment29	7.50	56.0	2.1×10^6	0.16	−0.2	0.02
Embodiment30	7.51	56.0	1.8×10^6	0.20	−0.1	0.03

[Table 2 continue]

	Density g/cm^3	Hardness HRC	Frequency of occurrence of pitting	Wear loss μm / 1 × 10^5 times	Rate of dimensional change %(absolute value)	Cam lift errors mm(absolute value)
Comparative example1	7.10	49.5	1.3×10^5	1.2	–	–
Comparative example2	7.45	52.0	3.0×10^5	0.6	−0.8	0.08
Comparative example3	7.35	47.0	4.0×10^5	1.1	−0.6	0.06
Comparative example4	7.40	41.0	8.0×10^4	2.3	−0.1	0.05
Comparative example5	7.46	48.0	3.0×10^5	1.5	−2.5	0.15

[0061]

(Consideration of measurement results)

(a) Effect of Ni (nickel) content (Embodiments 1 to 8, 16)

Embodiments 1 to 8 and 16 show test results of the density, hardness, frequency of occurrence of pitting, wear losses, rate of dimensional change and cam lift errors of alloys having Ni contents that are different from each other.

At the Ni contents of 0.5% to 5.0% the density, hardness and frequency of occurrence of pitting all tend to increase with increasing Ni content. As shown in FIG. 3, the density tends to increase little by little from 7.52 to 7.58 g/cm^3. As shown in FIG. 4, in the same manner as the density, the hardness also tends to increase little by little from 52.5 to 55.5 HRC. As shown in FIG. 5, the frequency of occurrence of pitting also tends to increase from 1.2×10^6 to 6.0×10^6.

At the Ni contents of 0.5% to 5.0% wear losses, which are 0.19 to 0.23 μm/1 × 10^5 times, show relatively small changes and are stable.

As shown in FIG. 6, at the Ni contents of 0.5% to 5.0% the rate of dimensional change, which is -0.1 to -0.5%, tends to increase little by little. As shown in FIG. 7, at the Ni contents of 0.5% to 5.0% cam lift errors, which are 0.02 to 0.05 mm, tend to increase little by little.

[0062]

(b) Effect of C (carbon) (Embodiments 9 to 12, 24, 25)

Embodiments 9 to 12, 24 and 25 show test results of the density, hardness, frequency of occurrence of pitting, wear losses, rate of dimensional change and cam lift errors of alloys having C contents that are different from each other.

As shown in FIG. 8, at a low C content of 0.5% the density is 7.55 g/cm^3 and somewhat high, the density tends to decrease with increasing C content, and at a high C content of 1.2% the density is 7.51 g/cm^3 and somewhat low. As shown in FIG. 9, in contrast to the density, at the C contents of 0.5% to 1.2% the hardness, which is 51.5 to 56.0 HRC, tends to increase.

At the C contents of 0.5% to 1.2% the frequency of occurrence of pitting, which 1.5 × 10^6 to 3.5 × 10^6, show relatively small changes and is stable. As with the frequency of occurrence of pitting, at the C contents of 0.5% to 1.2% wear losses, which are 0.16 to 0.25 μm/1 × 10^5 times, show relatively small changes and are stable. At the C contents of 0.5% to 1.2% the rate of dimensional change, which is -0.1

to -0.4%, tends to increase a little. At the C contents of 0.5% to 1.2% cam lift errors, which are 0.01 to 0.03 mm, show relatively small changes and are stable.

[0063]

(c) Effect of P (phosphorus) (Embodiments 1, 13 to 15)

Embodiments 1, 13 to 15 show test results of the density, hardness, frequency of occurrence of pitting, wear losses, rate of dimensional change and cam lift errors of alloys having P contents that are different from each other.

The relationships between the P content and the density, hardness and frequency of occurrence of pitting show the same tendency as in the case of Ni. As shown in FIG. 10, at the P contents of 0.05% to 0.3% the density, which is 7.51 to 7.54 g/cm^3, tends to increase little by little. As shown in FIG. 11, at the P contents of 0.05% to 0.3% also the hardness, which is 52.0 to 54.0 HRC, tends to increase little by little in the same manner as the density. Also, as shown in FIG. 12, at the P contents of 0.05% to 0.3% the frequency of occurrence of pitting, which is 8.5×10^5 to 1.5×10^6, tends to increase.

At the P contents of 0.05% to 0.3% wear losses, which are 0.20 to 0.23 μm/1×10^5 times, show relatively small changes and are stable. As with wear losses, at the P contents of 0.05% to 0.3% the rate of dimensional change, which is -0.1 to -0.2%, shows relatively small changes and are stable. At the P contents of 0.05% to 0.3% cam lift errors, which are 0.02 to 0.03 mm, show relatively small changes and are stable.

[0064]

(d) Effect of B (boron) (Embodiments 10, 17 to 19)

Embodiments 10, 17 to 19 show test results of the density, hardness, frequency of occurrence of pitting, wear losses, rate of dimensional change and cam lift errors of alloys having B contents that are different from each other.

As shown in FIG. 13, at the B contents of 0.02% to 0.3% the density, which is 7.51 to 7.53 g/cm^3, shows small changes and is stable. As shown in FIG. 14, at the B contents of 0.02% to 0.3% the hardness, which is 53.0 to 54.0 HRC, shows small changes and is stable as with the density.

At the B contents of 0.02% to 0.3% the frequency of occurrence of pitting, which is 2.0×10^6 to 3.2×10^6, shows relatively small changes and is stable. At the B contents of 0.02% to 0.3% wear losses, which are 0.21 to 0.24 μm/1×10^5 times, show relatively small changes and are stable. As with wear losses, at the B contents of 0.02% to 0.3% the rate of dimensional change, which is -0.2 to -0.4%, shows relatively small changes and are stable. At the B contents of 0.02% to 0.3% cam lift errors, which are 0.02 to 0.04 mm, show relatively small changes and are stable.

[0065]

(e) Effect of Mo (molybdenum) (Embodiments 6, 20 to 23, 26 to 30)

Embodiments 6, 20 to 23, 26 to 30 show test results of the density, hardness, frequency of occurrence of pitting, wear losses, rate of dimensional change and cam lift errors of alloys having Mo contents that are different from each other.

As shown in FIG. 15, at a low Mo content of 0.3% the density is 7.54 g/cm^3 and somewhat high, the density tends to decrease with increasing Mo content, and at a high Mo content of 2.5% the density is 7.50 g/cm^3 and somewhat low because compressibility worsens greatly. As shown in FIG. 16, at the Mo contents of 0.3% to 2.5% the hardness, which is 55.5 to 56.5 HRC, is somewhat high because of increased hardenability, shows small changes and is stable.

At the Mo contents of 0.3% to 2.5% the frequency of occurrence of pitting, which is 1.8 × 10^6 to 2.5 × 10^6, show relatively small changes and is stable. At the Mo contents of 0.3% to 2.5% wear losses, which are 0.16 to 0.21 μm/1 × 10^5 times, are somewhat low, show relatively small changes and are stable. At the Mo contents of 0.3% to 2.5% the rate of dimensional change, which is 0 to -0.3%, shows relatively small changes and is stable. At the Mo contents of 0.3% to 2.5% cam lift errors, which are 0.02 to 0.04 mm, show relatively small changes and are stable.

[0066]

(f) Various combinations of Ni, B and Mo (Embodiments 24 to 29)

Embodiments 24 to 29 show test results of the density, hardness, frequency of occurrence of pitting, wear losses, rate of dimensional change and cam lift errors of alloys having Ni, B and Mo contents that are different from each other.

Consideration will be given to results of various tests conducted in combinations of Ni contents of 1.0% to 3.5%, B contents of 0.05 to 0.2% and Mo contents of 0.3% to 2.0%.

Because density is affected by Mo, there is scarcely any effect even if the Ni and B contents are changed and the density develops at relatively low and medium levels of 7.50 to 7.54 g/cm^3. Because the C content is somewhat high and hardness is affected by Mo, the hardness develops at relatively high levels of 55.5 to 56.5 HCR.

Because density is affected by Mo and also due to the effect of Ni, the frequency of occurrence of pitting develops in a wide range of 1.8×10^6 to 3.5×10^6. The C content is somewhat high and the hardness is somewhat high because hardness is affected by the synergistic effect of C and Mo. Therefore, wear losses develop at relatively low levels of 0.16 to 0.21 $\mu m/1 \times 10^5$ times.

The rate of dimensional change, which is affected by Ni, develops in a wide range of 0 to -0.4%. Cam lift errors, which are affected by Ni as with the rate of dimensional change, develop in a wide range of 0.01 to 0.04 mm.

[0067]

(g) Combination of B and P (Embodiment 30)

Embodiment 30 of Table 2 shows test results of the density, hardness, frequency of occurrence of pitting, wear losses, rate of dimensional change and cam lift errors of an alloy in which a combination of B and P is used.

Because the C and Mo contents are somewhat high, the density is somewhat low and conversely, the hardness is somewhat high. Therefore, the frequency of occurrence of pitting and wear losses develop at intermediate levels of the ranges of the above-described embodiments, the rate of dimensional change is somewhat low, and cam lift errors are somewhat high. Thus, even a combination of B and P is used, the density and hardness in the ranges of the invention were obtained and good results were obtained also in other items.

[0068]

(h) Comparative examples

Embodiments 1 to 30 were superior to all of Comparative Examples 1 to 5.

Comparative Example 2 is not included in the present invention in that neither B nor P is contained. As a result of this, Comparative Example 2 had lower density and frequency of occurrence of pitting than in each embodiment and was inferior in pitting resistance. Also, Comparative Example 2 had a larger wear loss than in each embodiment and was inferior in wear resistance. Because Comparative Example 2 was produced by performing compression once and sintering once (this method is hereinafter called 1P1S), the rate of dimensional change was higher than in each embodiment and cam lift errors were also somewhat higher than in each embodiment. Thus, Comparative Example 2 was inferior in both the rate of dimensional change and cam lift errors.

Comparative Example 3 is not included in the present invention in that Ni is not contained. As a result of this, Comparative Example 3 had lower density and frequency of occurrence of pitting than in each embodiment and was inferior in pitting resistance. Also, because Comparative Example 3 had lower density and hardness than in each embodiment, it had a larger wear loss than in each embodiment and was inferior in wear resistance. Because Comparative Example 3 was produced by 1P1S, it had a rate of dimensional change somewhat higher than in each embodiment and also a cam lift error somewhat higher than in each embodiment. Thus, Comparative Example 3 was inferior in both the rate of dimensional change and cam lift errors.

Comparative Example 4 is not included in the present invention because its C, Ni and P contents are lower than the respective contents specified in the invention. As a result of this, Comparative Example 4 had lower density and frequency of occurrence of pitting than in each embodiment and was still inferior to Comparative Examples 2 and 3 described above in pitting resistance. Also, because Comparative Example 4 had lower density and hardness than in each embodiment, it had a larger wear loss than in each embodiment and Comparative Examples 2 and 3 described above and was very inferior in wear resistance.

Comparative Example 5 is not included in the present invention because its C, Ni and P contents are higher than the respective contents specified in the invention. As a

result of this, as with Comparative Examples 2 and 3, Comparative Examples 5 had lower density and frequency of occurrence of pitting than in each embodiment and was inferior in pitting resistance. Also, because of lower density and hardness than in each embodiment, Comparative Example 5 had a larger wear loss than in each embodiment and was inferior in wear resistance. Furthermore, because Comparative Example 5 was produced by 1P1S, it had a rate of dimensional change very higher than in each embodiment and also a cam lift error very higher than in each embodiment. Thus, Comparative Example 5 was inferior in both the rate of dimensional change and cam lift errors.